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# Chapter 1

## Introduction

*I think there is no sense in forming an opinion when there is no evidence to form it on. If you build a person without any bones in him he may look fair enough to the eye, but he will be limber and cannot stand up; and I consider that evidence is the bones of an opinion.*

**Mark Twain**

*in Personal Recollections of Joan of Arc*



**T**oday a student writing a paper on the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500, later to be known as the Clean Water Act or CWA) would be hard-pressed to find a public official who would say the legislation was not a success. Vice President Gore's remarks in October 1997 celebrating the 25th anniversary of the act are representative of the good feelings people have about the CWA (USEPA, 1997a; WEF, 1997).

In his speech the Vice President lauded the cooperative efforts of federal, state, tribal, and local governments in implementing the act's pollution control provisions. He reported that the quality of rivers, lakes, and bays has "improved dramatically." He related success stories involving water-based commerce, agriculture, tourism, fisheries, and quality of life for a variety of locations, including Alaska's St. Paul Harbor, the Chesapeake Bay, Cleveland's Cuyahoga River, the Long Island Sound, and the Houston Ship Channel. With cheers like that ringing in people's ears, it's no wonder that the prevailing public opinion is one of success. But what if the paper-writing student were to inquire skeptically about the "bones" of this opinion? What scientific evidence could she cite to back up this claim? *Was the Nation indeed able to buy water quality success with the approximately \$200.6 billion in capital costs and \$210.1 billion in operation and maintenance costs (current year dollars) invested from 1972 to 1994 by public and private authorities in point source water pollution control?*

A centerpiece of the CWA was a dramatic increase in federal support for upgrading publicly owned treatment works (POTWs). From 1970 to 1999, \$77.2 billion in federal grants and contributions through the U.S. Environmental Protection Agency's (USEPA's) Construction Grants and Clean Water State Revolving Fund (CWSRF) programs was distributed to municipalities and states for this activity. A 1995 editorial in the Water Environment Federation's research journal noted that no comprehensive national study has ever been done to document whether this investment has paid off in terms of improved water quality (Mearns, 1995). Who could blame the student, then, if she applied Mark Twain's logic and concluded that the public's opinion concerning the success of the CWA was "limber" and could not "stand up."

The purpose of this study is to provide that student with the "bones" to form an opinion that will stand up. Specifically, it was designed to examine whether "significant" water quality improvements (in the form of increased dissolved oxygen [DO] levels) have occurred downstream from POTW discharges since the enactment of the CWA.

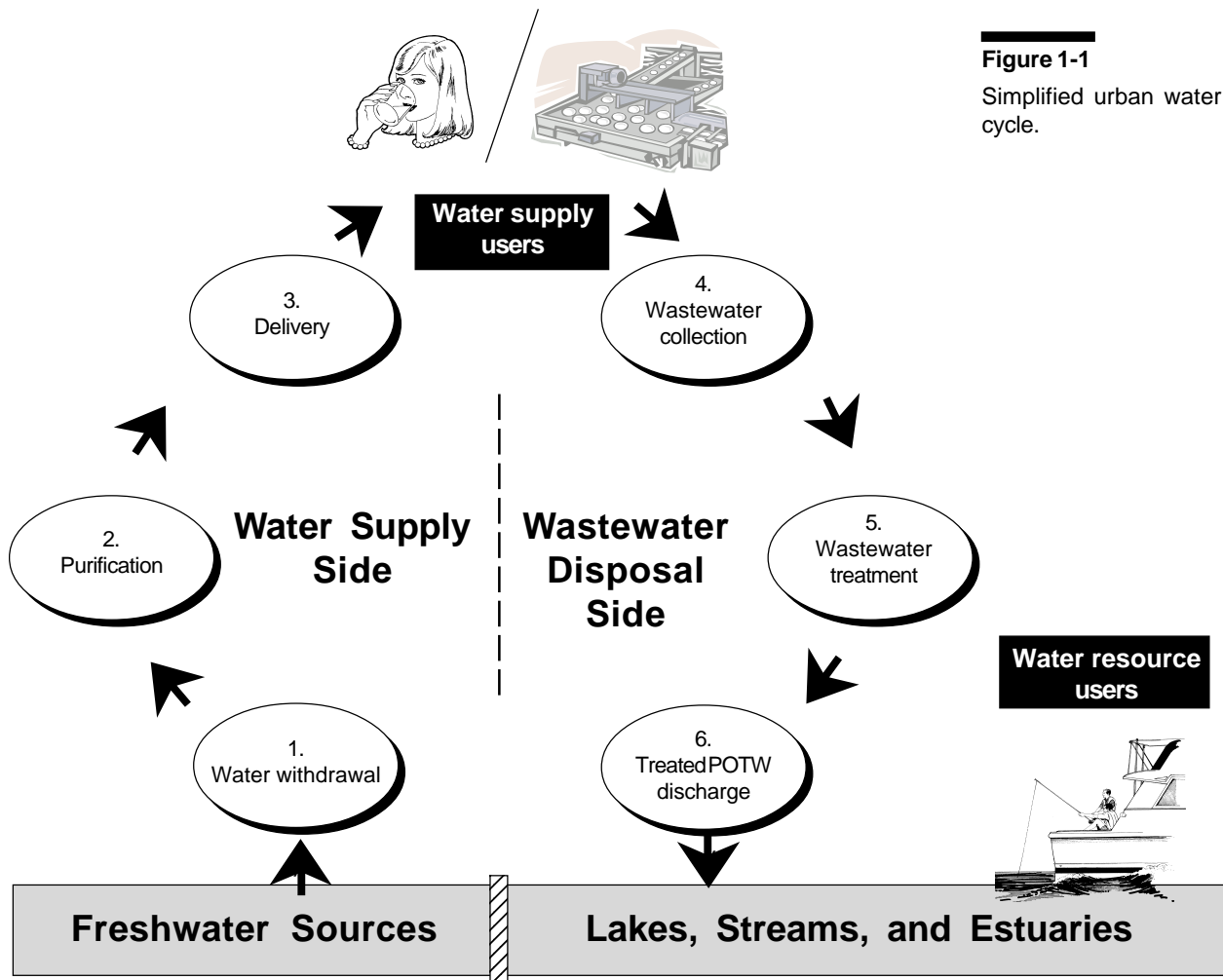
## **Background**

The framers of the CWA, drawing on the experience of the Ohio River Sanitation Commission, recognized that two basic sets of users depend on the chemical, physical, and biological integrity of the Nation's waterways.

1. *Water supply users*, people who take delivery of and use water drawn from various surface and ground water sources. Whether intentionally or not, these users usually contaminate the water they receive with pollutants such as organic matter, sediments, nutrients, pathogens, and heavy metals. Contaminated water (wastewater) is then collected, transported away from the site, treated, and returned back to a natural waterbody, where it can be withdrawn and cycled again by the same or another water supply system. Figure 1-1 illustrates this process, known as the *urban water cycle*.
2. *Water resource users*, people such as fishermen, boaters, and swimmers who use water in its natural settings—lakes, streams, rivers, and estuaries. This category might even be assumed to encompass the fish, waterfowl, and other living things that depend on clean water to live, reproduce, and thrive. These users can be directly affected by the return flow of wastewater from water supply users.

Meeting the needs of water supply and water resource users has been a problem that has vexed public officials for centuries. Only in the latter part of the 20th century did it become clear that the secret for keeping both sets of users satisfied is to have all components of the cycle in place and functioning properly. This fundamental concept played a pivotal role in the development of the CWA.

By the mid-1900s it was becoming more and more apparent that the weak link in the urban water cycle was the wastewater treatment component. Many communities were effectively short-circuiting the cycle by allowing raw or nearly raw sewage to flow directly into lakes, streams, rivers, estuaries, and marine waters. The organic matter contained in this effluent triggered increased growths of bacteria and corresponding decreases in DO levels. This situation, in turn,



**Figure 1-1**  
Simplified urban water cycle.

negatively affected the life functions of fish, shellfish, and other aquatic organisms. In addition, pathogens, nutrients, and other pollutants present in wastewater made body contact unsafe, increased the growth of algae and rooted aquatic plants, and reduced the potential for recreation and other uses. In sum, this weak link in the urban water cycle was greatly affecting the lives and livelihoods of water resource users downstream from POTWs.

Through the 1972 CWA, Congress aimed to remedy this situation by establishing a national policy requiring *secondary treatment* of municipal wastewater as the minimum acceptable technology, supplemented by more stringent water quality-based effluent controls on a site-specific, as-needed basis. At that time approximately 4,859 systems in the country serving 56.8 million people were providing only raw discharge or *primary treatment* of wastewater, a method that uses physical processes of gravitational settling to separate settleable and floatable solids from raw sewage. Secondary treatment, in contrast, yields a much cleaner effluent because it uses biological processes to break down much of the organic matter contained in the wastewater before allowing the wastewater to leave the facility.

Between 1970 and 1995 a total of \$61.1 billion (in current year dollars, equivalent to \$96.5 billion as constant 1995 dollars) was allocated by Congress through USEPA's Construction Grants Program for the purpose of building new, and upgrading old, POTWs. An additional \$16.1 billion in federal contributions was also distributed to states through the CWSRF from 1988 through 1999. In addition to this federal expenditure, state and local governments and private industry made significant investments to comply with regulations of the CWA and other state and local environmental legislation. On a nationwide basis, actual expenditure data compiled by the U.S. Department of Commerce, Bureau of Economic Analysis, in the annual *Pollution Abatement Cost Expenditures* documents a cumulative public and private sector capital expenditure of approximately \$200.6 billion and an additional \$210.1 billion as operating expenditures (current year dollars) for water pollution control activities during the period from 1972 through 1994 (Vogan, 1996). In this context, the Construction Grants Program provided federal grant support to local municipalities that amounted to almost one-half of the public sector costs and about one-third of the total public and private sector capital investment for water pollution control.

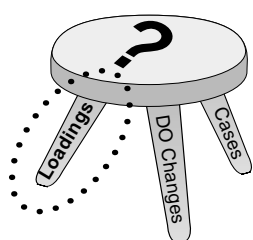
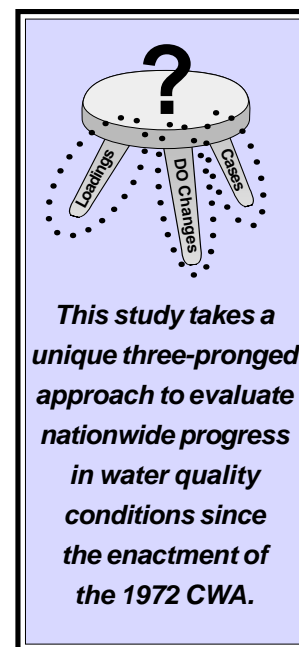
## **Study Approach**

For years, members of Congress, as well as citizens and special interest, environmental, and business groups, have been quizzing the USEPA about the benefits gained from the Nation's extraordinary public and private investment in wastewater treatment (GAO, 1986a, 1986b, 1986c; USEPA, 1988). Addressing their questions is a difficult task because environmental systems are very complex—so complex, in fact, that researchers can't even agree what "stick" to use to measure success. Consequently, a number of tools have been applied in an attempt to measure the success of water pollution control efforts. These include

- Reporting the number of discharge permits issued, enforcement actions taken, and other administrative actions and programmatic evaluations (Adler et al., 1993).
- Reporting on the number of POTWs built or upgraded, population served by various treatment levels, effluent loading rates, and other trends in the construction and use of wastewater infrastructure (USEPA, 1997b).
- Inventorying state and national waterways meeting designated uses (e.g., reports prepared by states to comply with CWA section 305(b), USEPA's 305(b) summary reports to Congress) (ASIWPCA, 1984; USEPA, 1995a, 1995b).
- Investigating changes in specific waterways following wastewater treatment plant upgrades (GAO, 1978, 1986c; Leo et al., 1984; Patrick et al., 1992).
- Investigating the statistical significance of national-scale changes in water quality following the 1972 CWA (GAO, 1981; Knopman and Smith, 1993; Smith et al., 1987a, 1987b).

Although each of the above approaches provides some evidence of the accomplishments of municipal wastewater treatment under the CWA, none could be considered a comprehensive assessment of national progress in meeting the CWA's main goal of maintaining, or restoring, fishable and swimmable waters. Clearly, a fresh measuring stick is needed—one that is simple enough to provide nonscientists with evidence of the overall success or failure of the act, yet rigorous enough to stand up to the scrutiny of people who make their living analyzing water quality data trends.

This study takes a unique, three-pronged approach for answering the *prima facie* question—*Has the Clean Water Act's regulation of wastewater treatment processes at POTWs been a success?* Or posed more directly, *How have the Nation's water quality conditions changed since implementation of the 1972 CWA's mandate for secondary treatment as the minimum acceptable technology for POTWs?* The three-pronged approach described below was developed so that each study phase could provide cumulative support regarding the success, or failure, of the CWA-mandated POTW upgrades to at least secondary treatment. Using the analogy of a three-legged stool, the study authors believed that each leg must contribute support to the premise of CWA success. If one or more legs fail in this objective, the stool will, in the words of Mark Twain, be “limber” and unable to “stand up.”



## The First Leg: An Examination of BOD Loadings Before and After the CWA (Chapter 2)

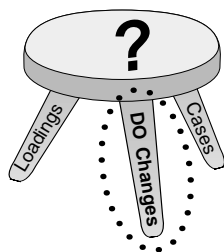
Biochemical oxygen demand (BOD) is a measurement that allows scientists to compare the relative polluting strength of different organic substances. The widest application of the BOD test, however, is for measuring waste load concentrations to (influent load) and discharged from (effluent load) POTWs and other facilities and evaluating the BOD-removal efficiency of these treatment systems. From 1970 to 1999, \$77.2 billion (as current year dollars) in federal grants and contributions through USEPA's Construction Grants and CWSRF programs was distributed to municipalities and states to upgrade POTWs and, among other objectives, to increase their BOD-removal efficiency. *Did this investment pay off in terms of decreasing BOD effluent loadings to the Nation's waterways?* The purpose of the first leg of this study is to examine nationwide trends in both influent and effluent BOD loadings before and after the CWA.

Chapter 2 begins with some background discussions to help the reader better understand the significance of the wastewater component of the urban water cycle and the pivotal role the 1972 CWA played in establishing the national policy requiring secondary treatment as the minimum acceptable technology for this component. Specifically, *Sections A* and *B* trace some historical consequences of not incorporating the wastewater treatment component of the urban water cycle. Beginning with ancient Athenians and moving through time, societies around the world suffered the results of releasing raw or inadequately treated sewage into waterways, including outbreaks of disease and the destruction of

fragile aquatic ecosystems. Sparked by the Lawrence (Massachusetts) Experiment Station's discovery of the trickling filter method in 1892 and the development of the BOD test in the 1920s, many states subsequently adopted water quality standards and encouraged the use of secondary treatment for the purpose of protecting their waterways and water supply and water resource users. Unfortunately, rapidly growing urban populations and uneven applications of wastewater treatment funding and technology caused conditions to deteriorate in many highly populated watersheds in the first two-thirds of the 20th century. *Section C* of this chapter traces the evolution of the federal government's role in water pollution control during this time period. Key legislation is highlighted to document its movement from passive advisor through to the passage of the 1972 CWA, the decisive legislation that transferred authority for directing and defining water pollution control policy and initiatives from the states to USEPA. Post-1972 legislation and regulations continue to refine water pollution control goals and objectives and authorize the funding and policies necessary to meet them.

Twenty-five years after the passage of the CWA, the number of people served by POTWs has increased from about 140 million in 1968 to 189.7 million in 1996. *In spite of this population increase (and corresponding increases in the amount of BOD flowing into these facilities), has there been a significant decline in BOD loading to the Nation's waterways?* *Section D* examines trends in influent and effluent BOD loading from 1940 to 1996 based on population served and BOD removal rates associated with various treatment levels.

*Section E* helps put POTW effluent BOD loading into national perspective by examining rates and spatial distribution of BOD loadings associated with other point and nonpoint sources of BOD in addition to municipal loadings. Using USEPA's National Water Pollution Control Assessment Model (NWPCAM) (Bondelid et al., 1999), loading estimates were derived for urban and rural runoff, combined sewer overflows, and industrial wastewater discharges, in addition to municipal discharges. Comparison of these sources at a national level provides insight on how total BOD loading is distributed among sources in various regions of the United States. *Section F* presents a discussion of the investment costs associated with water pollution control infrastructure over the time period 1970 to 1999 and summarizes projections of future wastewater infrastructure needs into the 21st century.



## **The Second Leg: An Examination of “Worst-Case” DO in Waterways Below Point Sources Before and After the CWA (*Chapter 3*)**

Professionals in the water resource field use many different parameters to characterize water quality. If one's interest centers on protecting fish and other aquatic organisms, however, DO concentration is a key parameter to focus on. This interest is articulated in section 101 of Title I of the Clean Water Act in the

**Table 1-1.** USEPA water quality criteria for dissolved oxygen concentration

	Cold-water biota		Warm-water biota	
	Early life stages <sup>a,b</sup>	Other life stages	Early life stages <sup>b</sup>	Other life stages
30-day mean	NA <sup>c</sup>	6.5	NA	5.5
7-day mean	9.5 (6.5)	NA	6.0	NA
7-day mean minimum	NA	5.0	NA	4.0
1-day minimum <sup>d</sup>	8.0 (5.0)	4.0	5.0	3.0

<sup>a</sup> Recommended water column concentrations to achieve the required intergravel dissolved oxygen concentrations shown in parentheses. The figures in parentheses apply to species that have early life stages exposed directly to the water column.

<sup>b</sup> Includes all embryonic and larval stages and all juvenile forms to 30 days following hatching.

<sup>c</sup> NA—not applicable

<sup>d</sup> All minima should be considered instantaneous concentrations to be achieved at all times. Further restrictions apply for highly manipulative discharges.

form of a national goal for fishable waters. Fish kills are the most visible symptom of critically low levels of DO. Some species of fish can handle low levels of oxygen better than others. Cold-water fish (salmon, trout) require higher DO concentrations than warm-water fish (bass, catfish). Early life stages usually require higher DO concentrations than adult stages. Table 1-1 presents USEPA's water quality criteria for DO for cold-water and warm-water biota for four temporal categories. The reader should note that a DO concentration of 5 mg/L has been adopted in this study as a general benchmark threshold for defining desirable versus undesirable levels of DO (i.e., the minimum concentration to be achieved at all times for early life stages of warm-water biota).

The concentration of DO in a stream fluctuates according to many natural factors, including water temperature, respiration by algae and other plants, nitrification by autotrophic nitrifying bacteria, and atmospheric reaeration. By far the biggest factor in determining DO levels in most waterbodies receiving wastewater discharges, however, is the amount of organic matter being decomposed by bacteria and fungi. Twenty-five years after the passage of the CWA, the Nation's investment in upgrading POTWs to secondary or greater levels of treatment resulted in significant reductions in BOD loadings. *Has the CWA's push to reduce BOD loading resulted in improved water quality in the Nation's waterways?*

The challenge in evaluating the effectiveness of point source BOD loading reductions is the need to isolate their impacts on downstream DO from impacts caused by urban stormwater runoff and rural nonpoint sources and the natural seasonal influences of streamflow and water temperature. An innovative approach was developed to reduce these confounding factors and screen for water quality station records that inherently contain a "signal" linking point source discharges with downstream DO. It includes the following steps:

- Developing before- and after-CWA data sets of DO summary statistics derived from monitoring stations that were screened for worst-case conditions (i.e., conditions that inherently contain the sharpest signal).

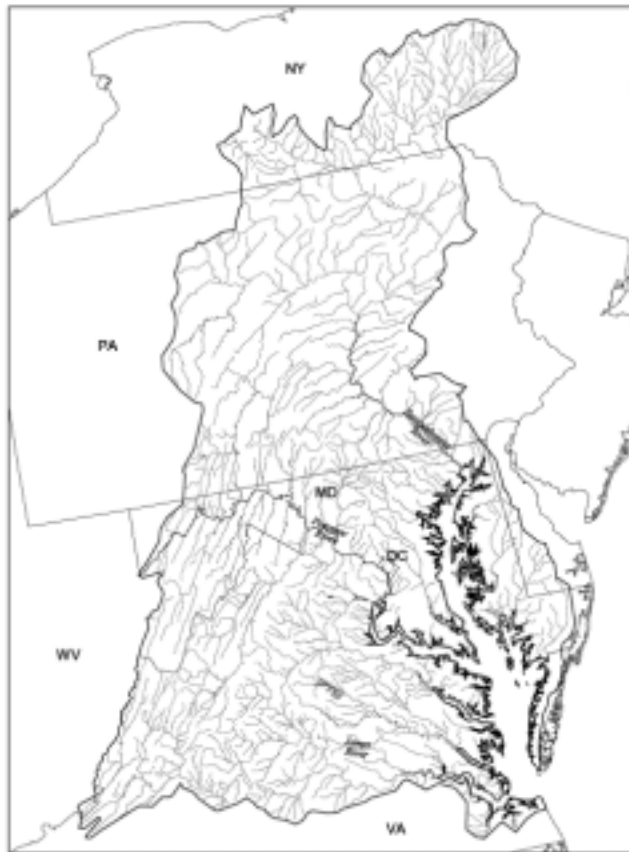
- Assigning the worst-case DO summary statistic to each station for each before- and after-CWA time period and then aggregating station data at sequentially larger spatial scales.
- Conducting a “paired” analysis of spatial units that have both a before- and an after-CWA worst-case DO summary statistic and then documenting the direction (improvement or degradation) and magnitude of the change.
- Assessing how the point source discharge/downstream worst-case DO signal changes over progressively larger spatial scales.

The hierarchy of spatial scale plays an especially important role in this second leg of the three-legged stool approach for examining water quality conditions before and after the CWA. Three spatial scales are addressed in this portion of the study: reach, catalog unit, and major river basin.

Reaches are segments of streams, rivers, lakes, estuaries, and coastlines identified in USEPA’s Reach File 1 (RF1). In this system, a reach is defined by the confluence of a tributary upstream and a tributary downstream. Reaches in RF1 average about 10 miles in length and have a mean drainage area of 115 square miles. Created in 1982, RF1 contains information for 64,902 reaches in the 48 contiguous states, covering 632,552 miles of streams. Figure 1-2 is a map of the stream reach network in the Chesapeake Bay drainage area.

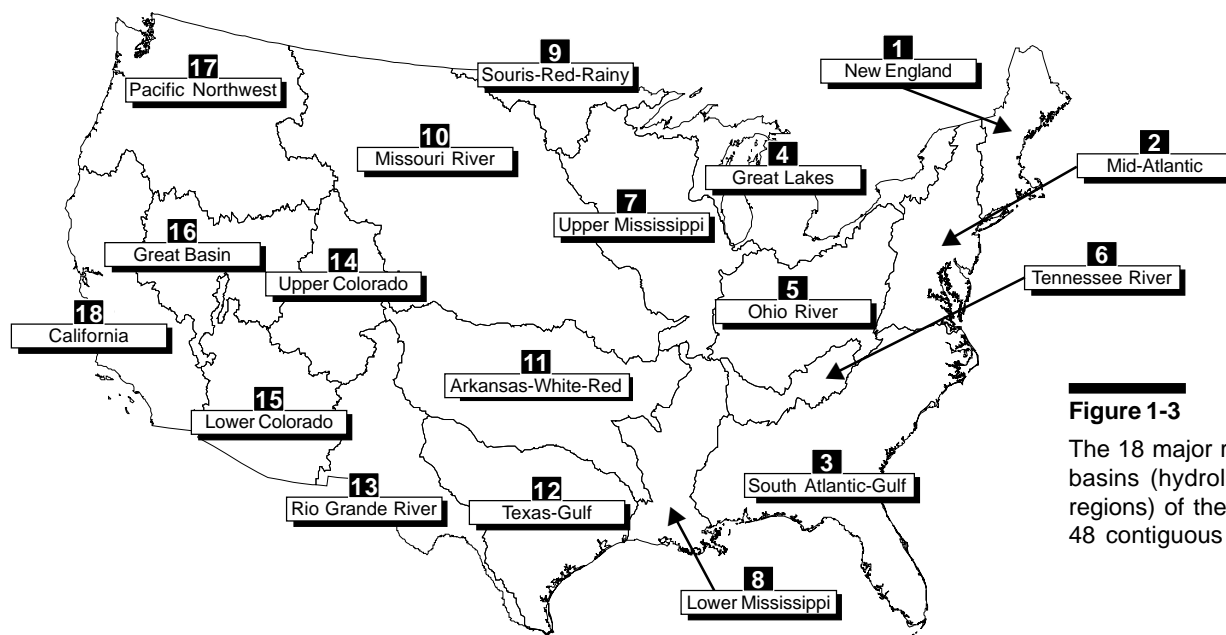
**Figure 1-2**

Reach File Version 1  
stream reach network in  
the Chesapeake Bay  
drainage area.





An individual reach in the RF1 system is identified by an 11-digit number. This number carries much spatial information. It identifies not only the reach itself, but also the hierarchy of watersheds to which the reach belongs. The first eight digits of the identification number are the hydrologic unit catalog (HUC) code. Originally developed by the U.S. Geological Survey (USGS), the HUC code identifies four scales of watershed hierarchy. The highest scale, coded in the first two digits of the identification number, is the hydrologic region (commonly referred to as a major river basin). Hydrologic regions represent the largest river basins in the country (e.g., the Missouri River Basin and the Tennessee River Basin). Subregions are identified by the next two numbers. These are followed by the accounting unit and the cataloging unit, the smallest scale in the hierarchy. Figures 1-3 and 1-4 display the 18 hydrologic regions and the 2,111 cataloging units in the contiguous 48 states.



**Figure 1-3**

The 18 major river basins (hydrologic regions) of the 48 contiguous states.



**Figure 1-4**

The 2,111 hydrologic catalog units of the 48 contiguous states.

**Table 1-2.** Station and reach identification codes: Reach File Version 1 (RF1)

Agency ID: .....	21MINN
Station ID: .....	MSU-815-BB15E58
Station Location: .....	Mississippi R @Lock & Dam#2 at Hastings
Major river basin name: .....	Upper Mississippi River
Major river basin ID: .....	07
Subbasin ID: .....	0701
Accounting Unit ID: .....	070102
Catalog Unit ID: .....	07010206
Reach ID: .....	07010206001
Station milepoint on reach .....	UM 815.5
Reach length (miles) .....	33.1
Upstream milepoint of reach (Minnesota R) .....	UM 844.7
Downstream milepoint of reach (St. Croix R) .....	UM 811.6

Developers of RF1 extended the 8-digit HUC code by three digits for the purpose of identifying the reaches within the cataloging unit. Table 1-2 is an example of the RF1 identification codes for a reach of the Upper Mississippi River near Hastings, Minnesota. This 33.1-mile reach is defined by the confluence of the Minnesota River (upstream) and the St. Croix River (downstream).

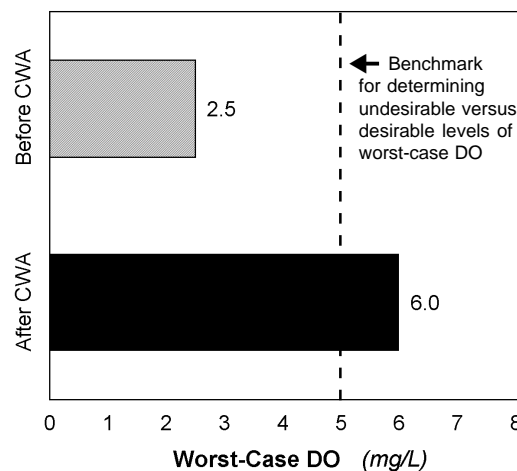
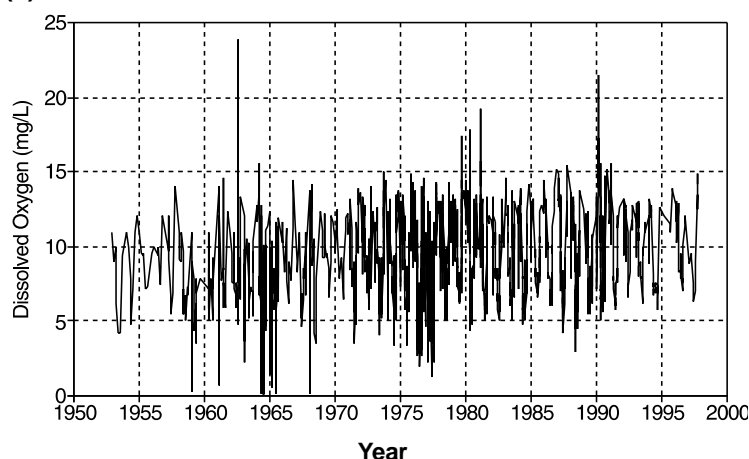
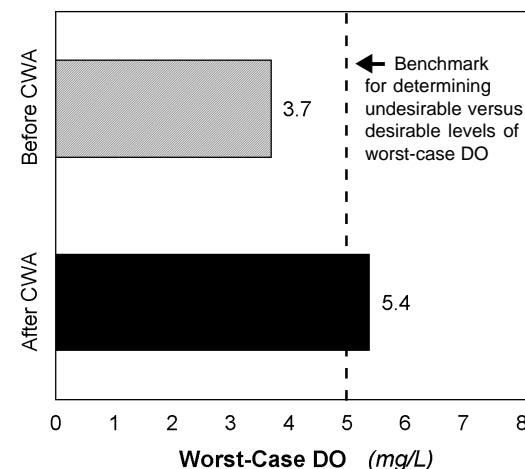
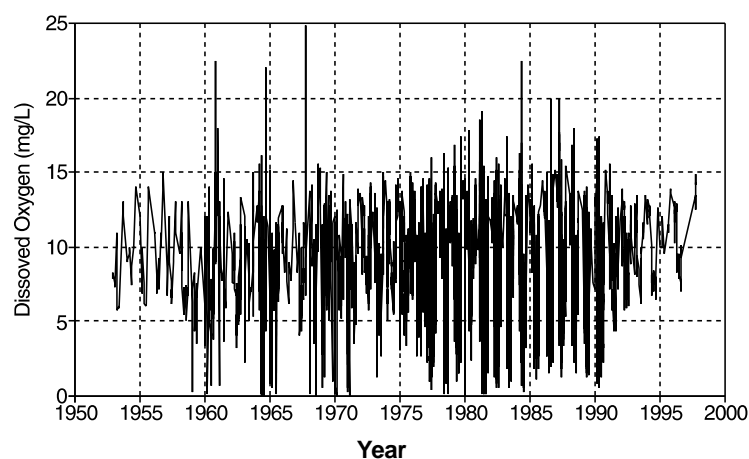
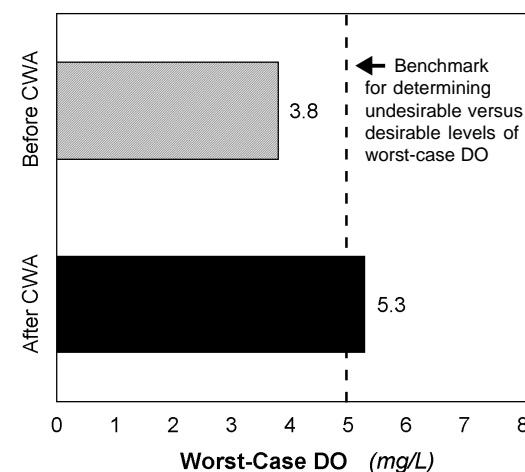
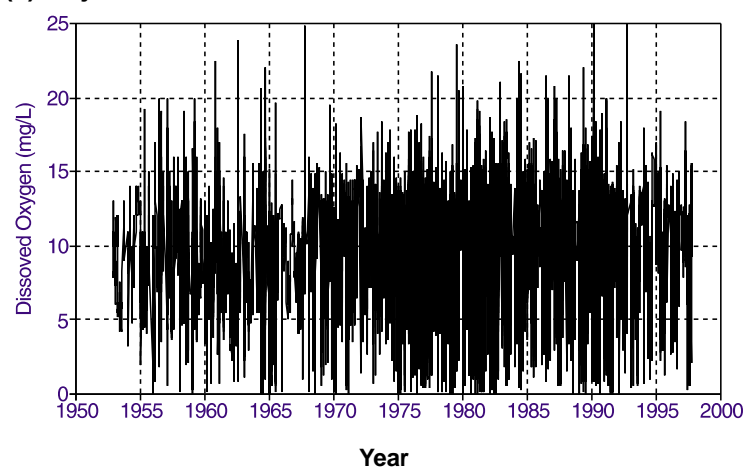
Many engineering studies have documented the impact of BOD loading on the DO budget in reaches immediately below municipal outfalls. Consequently, one would expect to find a sharp signal linking point source discharges with worst-case DO in those reaches. The key aspect of this investigation, therefore, was to see how the signal changed (or if it could be detected at all) as one aggregated worst-case DO data at increasingly larger spatial scales and then compared summary statistics associated with time periods before and after the CWA. Detection of a statistically significant signal at the catalog unit and major river basin scales would provide evidence that the CWA mandates to upgrade to secondary treatment and greater levels of wastewater treatment yielded broad as well as localized benefits.

Figure 1-5 illustrates signal and noise relationships over the range of spatial scales (reach, catalog unit, and major river basin) using the Upper Mississippi River near Hastings, Minnesota, as an example. The line graphs in the left side of the figure display DO data collected at monitoring stations from 1953 to 1997 aggregated by spatial unit. The bar graphs on the right side of the figure compare worst-case DO (mean 10th percentile) for designated time periods before and after the CWA and are produced as the final step of the comparison analysis process described in Chapter 3. The summary statistics they present are derived from station data that have been selected, aggregated, and spatially assessed so that they might have the best chance of inherently containing a “signal” linking point source discharges with downstream DO.

**Figure 1-5**

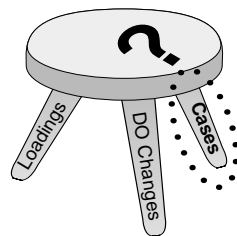
Line graphs of DO observations for the Upper Mississippi River from 1953 to 1997 and bar charts of worst-case DO before and after the CWA for (a) reach scale, (b) catalog unit scale, and (c) major river basin scale.

Source: USEPA STORET for (a) RF1 reach 07010206001 (UM 811.6-844.7), (b) catalog unit 07010206 (UM 811.6-879.8), and (c) major river basin (07).

**(a) Reach scale****(b) Catalog unit scale****(c) Major river basin scale**

Examining the line graphs in Figure 1-5, one can see that each broader spatial scale aggregation of station data yields a “noisier” data pattern. The bar chart for the reach scale (the finest scale) displays the greatest improvement in worst-case DO, increasing 3.5 mg/L from before to after the CWA. At the broader scales, an improvement is detected, but it is not as large (a before and after difference of 1.7 mg/L at the catalog unit scale and 1.5 mg/L at the major river basin scale). This is because the larger spatial units contain stations both near and far from point source outfalls. In spite of the unavoidable introduction of data noise, however, the signal linking point source discharge to downstream DO is still detectable at the broader scales using the data mining and statistical methodology developed by the study authors. Readers should note that in this example, the worst-case DO concentration was below the benchmark threshold of 5.0 mg/L at all three scales before the CWA and above the threshold at all three scales after the CWA.

*Section A* of Chapter 3 provides background on the relationship between BOD loading and stream water quality and discusses the two key physical conditions (high temperature and low flow) that create “worst case” conditions for DO. *Section B* describes the development and application of a set of screening rules to select, aggregate, and spatially assess before- and after-CWA worst-case DO data drawn from USEPA’s STORET database. *Section C* presents the results of the comparison analysis of worst-case DO from before and after the CWA for reach, catalog unit, and major river basin scales.



## **The Third Leg: Case Study Assessments of Water Quality (Chapters 4 through 13)**

The second leg of this study focused on the use of large national databases and statistical methods to examine temporal and spatial trends in DO conditions nationwide. However, the uniqueness of each waterway and the activities surrounding it requires an investigation to go beyond STORET to identify, quantify, and document in detail the specific actions that have resulted in water quality improvements and associated benefits to water resource users.

In the third and final leg of this study nine urban waterways have been selected to characterize changes in population, point source effluent loading, water quality, and environmental resources before and after the CWA:

- Connecticut River
- Hudson-Raritan estuary
- Delaware estuary
- Potomac estuary
- James estuary
- Chattahoochee River
- Ohio River
- Upper Mississippi River
- Willamette River

These waterways were selected to represent heavily urbanized areas with historically documented water pollution problems. A variety of data sources, including the scientific literature, USEPA's national water quality database (STORET), and federal, state, and local agency reports, were used to characterize long-term trends in population, point source effluent loading rates, ambient water quality, environmental resources, and recreational uses. Additional information was obtained from validated water quality models for the Delaware, Potomac, and James estuaries and Upper Mississippi River case studies to quantify the water quality improvements achieved by upgrading municipal facilities to secondary and better levels of treatment as mandated by the 1972 CWA.

Chapter 4 presents an overview of the case study assessment approach and provides background on previous efforts that have used case studies to examine long-term changes in water quality conditions in the United States. Chapter 4 also summarizes the overall findings for the nine urban waterways; detailed assessments are provided for each in Chapters 5 through 13.

## **The Audience For This Report**

This study was designed with two broad groups in mind. The primary audience are the technical scientists and engineers who try to understand and evaluate cause-effect relationships of pollutants, their sources, and the fate of these pollutants in receiving waters. Understanding these relationships is crucial for developing appropriate (cost-effective and environmentally protective) pollution control measures. This same audience is often tasked with the responsibility of developing and carrying out large-scale monitoring programs whose purpose is to gage the performance of various policy decisions related to pollution source control.

The secondary audience is Congress, regulatory/policy professionals, and the informed public who have often questioned the effectiveness of major pollution control programs directed at the national level. It may benefit future decisions makers to know if major public works programs (i.e., the CWA Construction Grants and CWSRF programs) accomplished what they were designed to do—namely reduce effluent BOD loads from municipal and industrial sources and improve dissolved oxygen in many previously degraded waterways of the Nation. These same groups also need to understand that water pollution control efforts are never ending. The 1972 CWA did not “solve” the problem. In fact, waste materials are generated continuously and effluent removal efficiencies must increase in the future to compensate for population growth. Planning for O&M expenditures as well as capital expenditures for replacement of obsolete facilities and upgrades to maintain adequate levels/efficiency of wastewater removal is an ongoing requirement. A projection analysis presented in Chapter 2 demonstrates that many of the gains in national water quality improvements may be lost if future wastewater infrastructure investments and capacity does not keep pace with expected urban population growth.

## References

- Adler, R.W., J.C. Landman, and D.M. Cameron. 1993. *The Clean Water Act: 20 years later*. Island Press, Washington, DC.
- ASIWPCA. 1984. *America's clean water: The states' evaluation of progress 1972-1982*. Executive Summary and Technical Appendix. Association of State and Interstate Water Pollution Control Administrators, Washington, DC.
- Bondelid, T., C. Griffiths, and G. Van Houten. 1999. *A national water pollution control assessment model*. Draft technical report prepared by Research Triangle Institute, Durham, NC, for U.S. Environmental Protection Agency, Office of Science and Technology, Washington, DC.
- GAO. 1978. *Secondary treatment of municipal wastewater in the St. Louis Area: Minimal impact expected*. GAO/CED-78-76. U.S. General Accounting Office, Program, Evaluation and Methodology Division, Washington, DC.
- GAO. 1981. *Better monitoring techniques are needed to assess the quality of rivers and streams*. Vol.#1. Report to Congress. GAO/CED-81-30. U.S. General Accounting Office, Program, Evaluation and Methodology Division, Washington, DC.
- GAO. 1986a. *The Nation's water: Key unanswered questions about the quality of rivers and streams*. Vol. 1. GAO/PMED-86-6. U.S. General Accounting Office, Program, Evaluation and Methodology Division, Washington, DC.
- GAO. 1986b. *Water quality: An evaluation method for the Construction Grants Program—methodology*. Vol. 1. Report to the Administrator. GAO/PMED-87-4A. U.S. General Accounting Office, Program, Evaluation and Methodology Division, Washington, DC.
- GAO. 1986c. *Water quality: An evaluation method for the construction grants program-case studies*. Vol. 1. Report to the Administrator. GAO/PMED-87-4B. U.S. General Accounting Office, Program, Evaluation and Methodology Division, Washington, DC.
- Knopman, D.S. and R.A. Smith. 1993. Twenty years of the Clean Water Act: Has U.S. water quality improved? *Environment* 35(1):17-41.
- Leo, W.M., R.V. Thomann, and T.W. Gallagher. 1984. *Before and after case studies: Comparisons of water quality following municipal treatment plant improvements*. EPA430/9-007. Technical report prepared by HydroQual, Inc., for U.S. Environmental Protection Agency, Office of Water Programs, Washington, DC.
- Mearns, A. 1995. "Ready...shoot...aim! The future of water." Editorial. *WEF Water Env. Res.* 67(7):1019.
- Patrick, R., F. Douglass, D.M. Palavage, and P.M. Stewart. 1992. *Surface water quality: Have the laws been successful?* Princeton University Press, Princeton, NJ.
- Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987a. *Analysis and interpretation of water quality trends in major U.S. rivers, 1974-81*. Water-Supply Paper 2307. U.S. Geological Survey, Reston, VA.
- Smith, R.A., R.B. Alexander, and M.G. Wolman. 1987b. Water quality trends in the Nation's rivers. *Science* 235 (27 March 1987):1607-1615.

- USEPA. 1995a. *National water quality inventory: 1994 report to Congress*. EPA841-R-95-005. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
- USEPA. 1995b. *National water quality inventory: 1994 report to Congress. Appendices*. EPA841-R-95-006. U.S. Environmental Protection Agency, Office of Water, Washington, DC.
- USEPA. 1997a. *The Clean Water Act: A snapshot of progress in protecting America's waters*. Vice President Al Gore's remarks on the 25th Anniversary of the CWA. U.S. Environmental Protection Agency, Washington, DC.
- USEPA. 1997b. *1996 Clean Water Needs Survey: Conveyance, treatment, and control of municipal wastewater, combined sewer overflows and stormwater runoff. Summaries of technical data*. U.S. Environmental Protection Agency, Office of Water Program Operations, Washington, DC.
- USEPA. 1988. *POTW's and water quality: In search of the big picture: A status report on EPA's ability to address several questions of ongoing importance to the Nation's municipal pollution control program*. U.S. Environmental Protection Agency, Office of Water, Office of Municipal Pollution Control, Washington, DC.
- Vogan, C.R. 1996. *Pollution abatement and control expenditures, 1972-94. Survey of current business*. Vol. 76, No. 9, pp. 48-67. U.S. Dept. of Commerce, Bureau of Economic Analysis.
- WEF. 1997. *Profiles in water quality: Clear success, continued challenge*. Water Environment Federation, Alexandria, VA.

